PB87-103578

Removing 'Giardia' Cysts from Low Turbidity Waters by Rapid Rate Filtration

Colorado State Univ., Fort Collins

Prepared for

Environmental Protection Agency, Cincinnati, OH

1986

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA/600/J-86/138	2.
3. REC	PB87-103578
4. TITLE AND SUBTITLE REMOVING GIARDIA CYSTS FROM LOW TURBIDITY WATERS BY RAPID RATE FILTRATION (Journal Version)	5. REPORT DATE 1986
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) M.Y. Al-Ani,[1] D.W. Hendricks,[1] G.S. Logsdon,[2] C.P. Hibler[1]	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS [1]Colorado State Univ., Fort Collins, CO 80523 [2]USEPA, Cincinnati, OH 45268	10. PROGRAM ELEMENT NO.
	11. CONTRACT/GRANT NO. CR 808650-02
12. SPONSORING AGENCY NAME AND ADDRESS Water Engineering Research Laboratory- Cincinnati, OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, OH 45268	13. TYPE OF REPORT AND PERIOD COVERED Journal Article
	14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES
Project Officer, G.S. Logsdon
Journal American Water Works Association 78(5): 66-73, May 1986

16. ABSTRACT

Pilot-plant studies showed that when effective chemical pretreatment is employed in combination with rapid rate filtration, removals of turbidity, total coliform bacteria, and Giardia cysts from low turbidity waters may be greater than 80, 99.9, and 99.9 percent, respectively. Proper coagulation, however, requires the careful selection of chemicals and dosages. It was also observed that for waters having turbidity levels <1ntu, percent reduction of turbidity can serve as a surrogate indicator of the removal of Giardia cysts.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

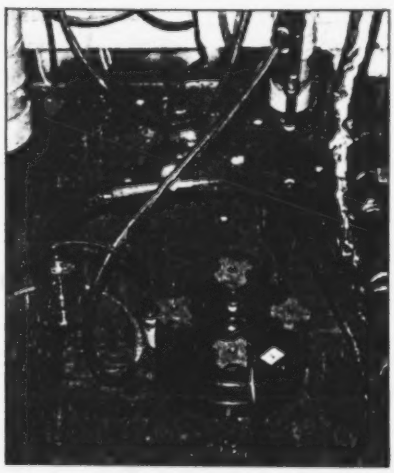
REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL
INFORMATION SERVICE
SPRINGFIELD, VA. 22161

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS (This Report) UNCLASSIFIED	21. NO. OF PAGES 10
	20. SECURITY CLASS (This page) UNCLASSIFIED	22. PRICE

EPA/600/J-86/138
JOURNAL ARTICLE

Removing *Giardia* Cysts From Low Turbidity Waters by Rapid Rate Filtration

Mohammed Y. Al-Ani, David W. Hendricks, Gary S. Logsdon, and Charles P. Hibler

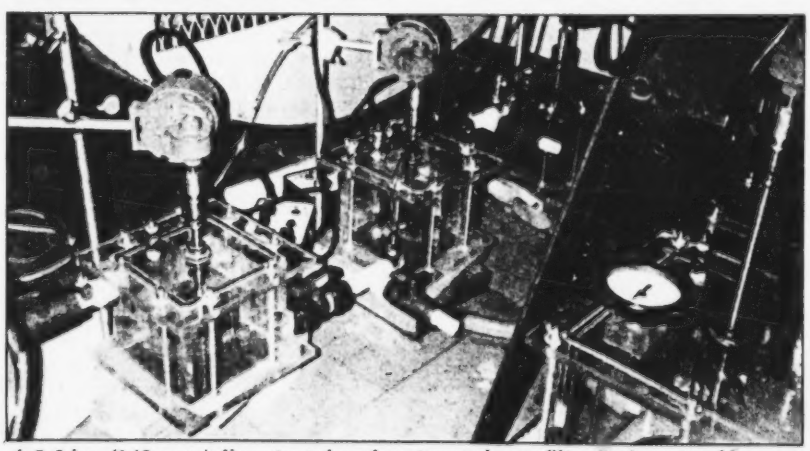


Pilot-plant studies showed that when effective chemical pretreatment is employed in combination with rapid rate filtration, removals of turbidity, total coliform bacteria, and *Giardia* cysts from low turbidity waters may be greater than 80, 99.9, and 99.9 percent, respectively. Proper coagulation, however, requires the careful selection of chemicals and dosages. It was also observed that for waters having turbidity levels <1 ntu, percent reduction of turbidity can serve as a surrogate indicator of the removal of *Giardia* cysts.

In the western United States, *Giardia lamblia* cysts have been found extensively in waters from mountain streams having turbidity levels <1 ntu. Such extensive occurrence was observed by C.P. Hibler during microscopic analysis of more than 3000 samples that had been obtained since 1976 by health departments and water utilities in various states. Although *Giardia* cysts are widespread in all kinds of waters, their occurrence in low turbidity waters is of special concern because of problems associated with the rapid rate filtration of these waters.

There are three kinds of problems associated with the rapid rate filtration of low turbidity waters (i.e., those with turbidities <1 ntu): (1) many treatment plant operators and engineers are unconvinced of the need to use chemicals, (2) there is little knowledge about the chemical pretreatment of low turbidity waters, and (3) evaluation of filtration efficiency is difficult.

The widespread occurrence of giardiasis, often associated with mountain streams, has highlighted these problems and has called attention to the fact that although the present drinking water standards are necessary, they are not sufficient. This is attested to by Hibler who observed cysts in more than 100 filtered waters produced from low turbidity raw waters, e.g., <1 ntu. Outbreaks of giardiasis have occurred under such conditions.[1]



A 5.6-in.- (142-mm-) diameter polycarbonate membrane filter (top) was used to obtain samples of Giardia *cysts from the filter effluent of the laboratory-scale pilot plant, which incorporated rapid mix basins (bottom), flocculation basins, and a sedimentation basin, as well as rapid rate filters.*

Objectives

The objectives of the research were (1) to determine how to chemically pretreat low turbidity water for efficient rapid rate filtration; (2) to determine the effect of process variables on the removal of *Giardia* cysts, turbidity, and bacteria; and (3) to ascertain whether use of a surrogate indicator is feasible for assess-

NTIS is authorized to reproduce and sell this report. Permission for further reproduction must be obtained from the copyright owner.

ing the efficiency of treatment for removing *Giardia* cysts.

The process variables included chemical pretreatment (coagulant selection and dosage); filtration mode (conventional, direct, or in-line); filter media; hydraulic loading rate; and temperature.

An ancillary objective was to determine the removal efficiency of rapid rate filtration when coagulation chemicals are not used.

Methods

Pilot plant. The laboratory-scale pilot plant was a dual-train, conventional, rapid rate filtration plant, built to be operated under pressure (Figure 1). The raw water was hauled from the Cache La Poudre River when water with a turbidity of <1 ntu could be obtained. When this was not possible, an artificial low turbidity water was used that had been prepared by treating water from Horsetooth Reservoir with diatomaceous earth filtration to remove turbidity-causing particles without changing the water's chemical quality. The two waters had similar chemical characteristics, e.g., pH of 7.5, alkalinity of 40 mg as $CaCO_3$/L, hardness of 40 mg as $CaCO_3$/L, and total dissolved solids of 50 mg/L. The raw water was stored in a 369.8-gal (1400-L), temperature-controlled milk cooler and then pumped by a positive-displacement pump, with a dampener to control pressure surges, to three rapid mix basins in series. The inside dimensions of each basin were 5 in. × 5 in. × 5 in. (12.7 cm × 12.7 cm × 12.7 cm). The stirring paddles had four rectangular blades, each measuring 0.5 in. × 0.5 in. (1.25 cm × 1.25 cm). The distance from the center of the stirring shaft to the outer edge of each blade was 1 in. (2.54 cm). The maximum rotational speed of the shaft was 600 rpm, giving a calculated G value of 400 s^{-1} at 20°C. The rotational speed could be varied by means of a rheostat that controlled the motor speed. Chemicals were metered by positive-displacement pumps capable of flows as low as 0.2 mL/min. Flows were measured volumetrically using 50-mL graduated burettes, which also served for chemical storage.

The flocculation basins had five stages, with each box measuring 8 in. × 8 in. × 8 in. (20.3 cm × 20.3 cm × 20.3 cm). The G for each basin could be controlled individually by a rheostat connected to the stirring motor. The basin could be operated using two, three, four, or five stages. The temperature was controlled by copper tubes in the bottom of the basin.

The sedimentation basin had a maximum detention time of 1.7 h, which could be reduced to 1.0 h. Copper tubes were installed for temperature control.

Four 72-in.- (183-cm-) long filter columns were connected to a manifold, which permitted one to four filters to be operated in any combination. Two of the filters were 2 in. (5 cm) in diameter, and two were 4 in. (10 cm) in diameter. Copper coils were installed in the top of the filters for temperature control. Tailwater elevation was controlled by overflow cups, which were maintained above the media. Head loss across the media was measured with a mercury manometer. Provision was made for backwash and for air scrubbing. Both a single medium of sand (30-in. [76-cm] depth) and dual media of anthracite and sand (17.7-in. [45-cm] and 11.8-in. [30-cm] depths, respectively) were used in the experiments.

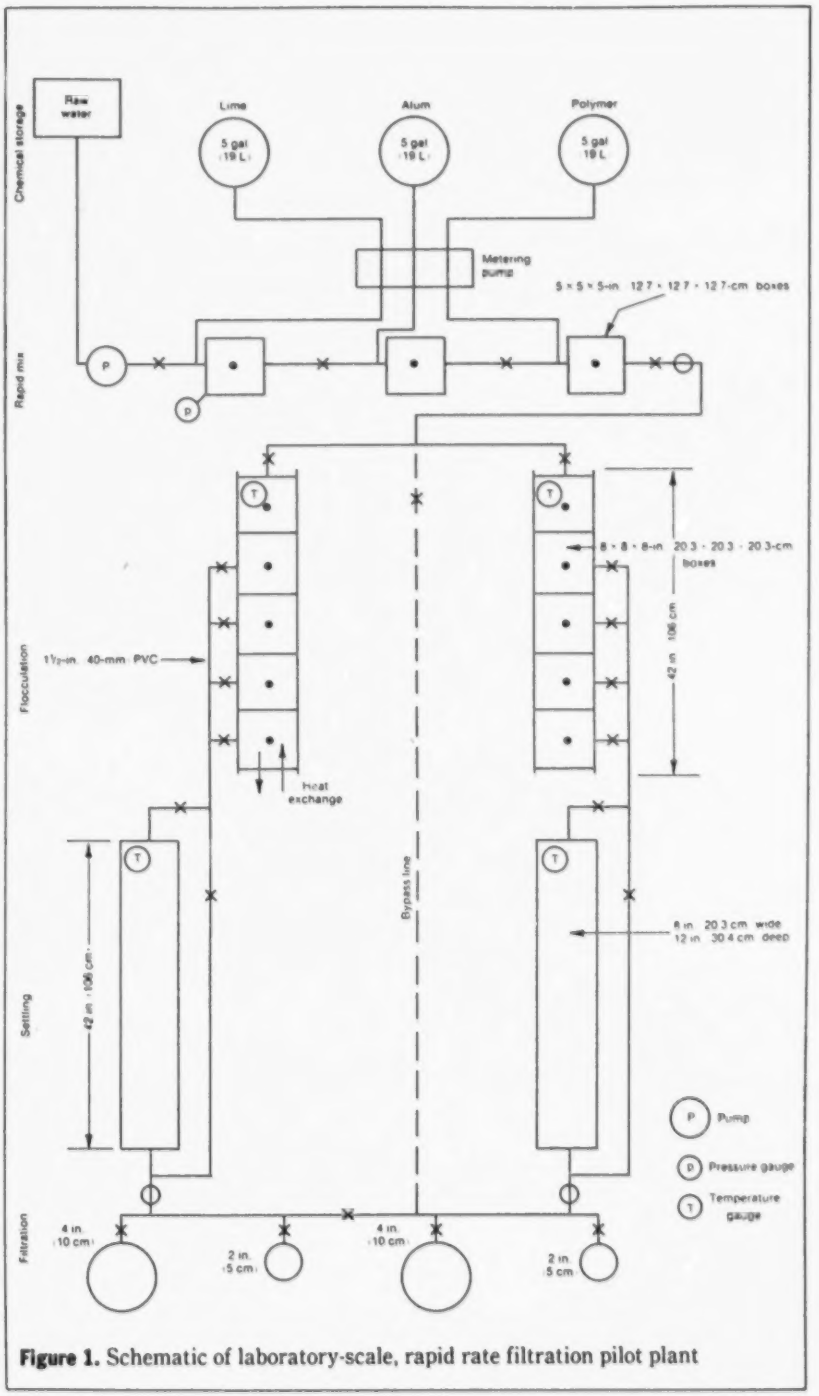


Figure 1. Schematic of laboratory-scale, rapid rate filtration pilot plant

The pilot plant could be operated in three modes of filtration: conventional (rapid mix, flocculation, sedimentation, filtration); direct (rapid mix, flocculation, filtration); and in-line (rapid mix, filtration). The in-line mode was used for the research except at the beginning when the effect of the direct filtration mode was explored.

TABLE 1

Process variables and operating conditions used during rapid rate filtration experiments

Process Variable	Operating Conditions
Raw water	Cache La Poudre River water, winter conditions, at <1 ntu
	Horsetooth Reservoir water treated with diatomaceous earth to reduce turbidity to <1 ntu
Temperature	37.4 and 64.4°F (3 and 19°C)
Coagulants	Alum
	Polymers: 572C,* 573C,* 8102†
Coagulant sequence	Alum added first then polymer
	Polymer added first then alum
	Alum and polymer in the same mixing basin
Filter media	Single medium: 30-in. (76-cm) sand bed, D_{10} = 0.43, UC = 1.5
	Dual media: 11.8-in. (30-cm) sand bed, D_{10} = 0.43, UC = 1.5; 17.7 in. (45 cm) anthracite, D_{10} = 0.9, UC = 1.5
	Dual media: 11.8-in. (30-cm) sand bed, D_{10} = 0.5, UC = 1.4; 17.7 in. (45 cm) anthracite, D_{10} = 0.9, UC = 1.5
Hydraulic loading rate	2, 5, 8 gpm/sq ft (4.9, 13.5, 19.2 m/h)
Pretreatment process	In-line mode, one or two stages of rapid mix with 180–290 s detention time, and G = 40–300 s^{-1} for each stage

*Magnifloc, American Cyanimid Co., Wayne, N.J.
†Nalco Chemical Co., Oak Brook, Ill.

Experimental design. The purpose of the pilot plant was to ascertain the effect of selected process variables (Table 1) on a group of dependent variables. Turbidity, *Giardia lamblia* cysts, total coliform bacteria, standard plate count bacteria, and particle count were the dependent variables selected for measurement. Figure 2 shows schematically an "*n*-dimensional testing space," which depicts the nature of the experimental task. The independent variables of interest are represented by the different axes at various angles.

The vertical line represents the collective "response" of the dependent variables selected for consideration. In other words, a set of independent (process) variables, imposed on the system as design or operating conditions, constitutes a particular set of stimuli. The responses of the dependent variables are then measured. If the process variables are changed systematically, varying one while holding the others constant, then functional relationships can be developed between the dependent variables and selected process variables.

The points at which tests were conducted are shown schematically in Figure 2 by the "tick marks" on the process variable lines. Within the range possible for each variable, tests were conducted only at selected points. Otherwise, the amount of testing would have been prohibitive. Even with these restrictions, 178 test runs were conducted over an 18-month period.

Economic aspects of filtration were beyond the scope of this research, as the focus was on removal efficiencies and the influences of process variables. Determining the cheapest coagulants and maximizing run lengths are concerns that should be addressed in future research. However, head loss versus time data for the test runs, which were usually 3–5 h, are given by Al-Ani et al.[2]

Sampling and analysis for *Giardia* cysts. The sampling technique followed to determine the concentration of *Giardia* cysts in the filter effluent was that used by Luchtel et al.[3] A 5.6-in.- (142-mm-) diameter polycarbonate membrane filter* with a 5-μm pore size was used. The entire flow from the rapid rate filter column was passed through the membrane filter. The total volume of water passed through the membrane filter was limited by the pressure buildup at the top of the filter column. Sampling was terminated when this pressure became 5 psi (34.4 kPa)—from about 0.1 or 0.2 psi (0.6 to 1.3 kPa) before the membrane filter was installed. About 5.2 gal (20 L) was usually passed through the membrane filter, but 36.9 gal (140 L) was passed in one test. When the pressure built up to about 5 psi (34.4 kPa), the membrane filter holder was disconnected from the filter effluent line, and the membrane was removed and washed, as outlined by Bellamy et al.[4] The sample was then sent to the laboratory, where the cysts were counted using a micropipette technique, as outlined by Hibler and described by Bellamy et al.[5]

To determine removals of *Giardia* cysts under a given set of filtration conditions, the milk cooler was spiked with several million cysts, obtained from the feces of infected dogs. These cysts were believed to be the species *Giardia lamblia*, as reported by Davies et al.[6] The cysts were separated from the feces by means of a cheesecloth technique and then refrigerated until needed for a test run. They were not stored for more than two weeks. During a test run, the milk cooler was spiked with the cysts, resulting in raw water concentrations of 500 to 5000 cysts/L.

To determine the concentration of cysts in the milk cooler, a sample was withdrawn using the 5-μm polycarbonate filter technique. About 5 to 20 L could usually be collected before the 5-psi (34.4-kPa) pressure loss across the filter membrane was exceeded.

Sampling and analysis for turbidity, bacteria, and particles. Sampling for turbidity, bacteria, and particles was by grab samples taken from the water in the milk cooler after it had been spiked with cysts and from the filter effluent stream after 30 min, after 60 min, and, for some tests, after 2 h of operation. Cuvettes were used for the turbidity samples, and sterile 250-mL plastic bottles were used for bacteria sampling. For particle sampling, 500-mL bottles were used. The cuvettes and bottles were cleaned and rinsed with distilled water passed through 0.2-μm filters.

Turbidity measurements were obtained with a ratio turbidimeter.† Concentrations of total coliform bacteria were measured using the membrane filter technique and according to a method described by the US Environmental Protection Agency.[7] Standard plate count bacteria were measured using a tryptone glucose extract agar.‡ Particles were measured with a particle counter.§

Results

Removal efficiency. Table 2 summarizes percent removals of turbidity, standard plate count bacteria, total coliform bacteria, particles, and *Giardia* cysts for low turbidity water at low temperatures, i.e., 35.6 to 39.2°F (2 to 4°C). Results of 21 test runs are shown for three categories of chemical pretreatment: (1) "none," in which no chemicals were used; (2) "nonoptimum," in which a nonoptimum chemical dosage, as determined by turbidity removal, was used; and (3) "optimum," in which an optimum chemical dosage, as measured by turbidity removal, was used.

All chemicals were added to the rapid mix basins, except polymer 8102, which was injected into the pipeline ahead of the filter. This procedure was enacted to simulate the practice of using this polymer as a filter aid.

Raw water turbidity levels were 0.4 to 0.7 ntu for water hauled from the Cache La Poudre River and 0.2 to 0.6 ntu for artificial low turbidity water obtained by diatomaceous earth filtration of Horsetooth Reservoir water.

For the eight tests in which coagulants were not added, removals of all param-

*Nuclepore Corp., Pleasanton, Calif.
†Model 18900, Hach Co., Loveland, Colo.
‡DF 0002-01-7, Difco Labs Inc., Detroit, Mich.
§Model TAII, Coulter Electronics, Opa Locka, Fla.

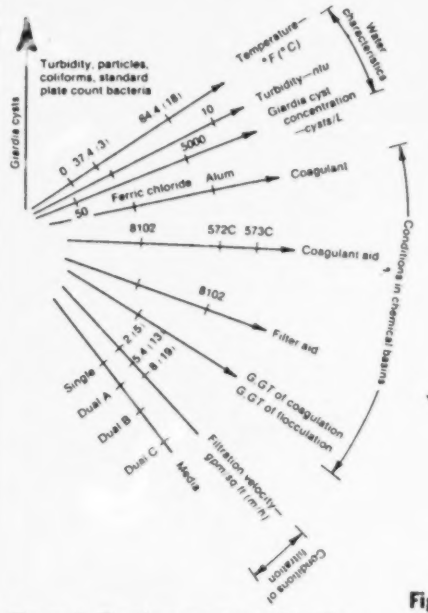


Figure 2. Testing space used to illustrate the range of the experimental work *(independent variables are shown collectively adjacent to the vertical axis; process variables are represented by the other axes)*

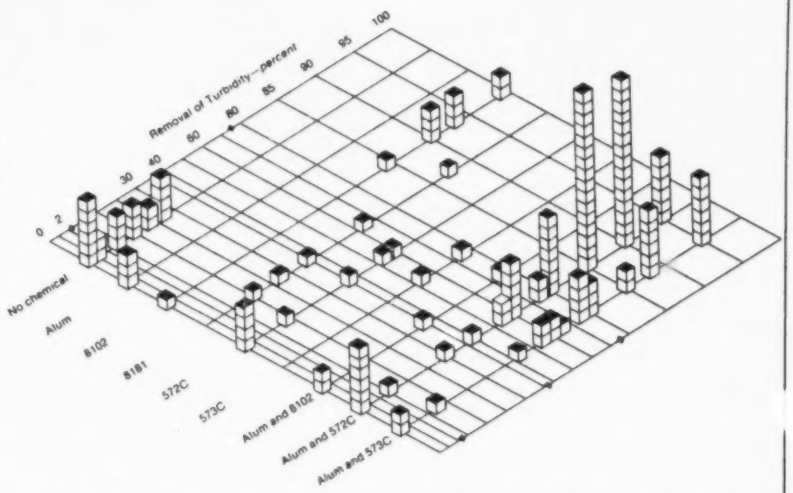


Figure 3. Histogram of percent removal of turbidity for coagulants tested *(each block represents one set of measurements; number of test runs—153; raw water turbidity—0.5-1.5 ntu; temperature—37.4-64.4°F [3-18°C])*

TABLE 2

Effect of chemical pretreatment on percent removals of turbidity, standard plate count bacteria, total coliform bacteria, particles, and Giardia *cysts*

	Conditions						Pretreatment			Removal—*percent*				
	Filter			Raw Water										
Run	Hydraulic Loading Rate *gpm/sq ft*	Hydraulic Loading Rate *m/h*	Media*	Source†	Temperature °F	Temperature °C	Category‡	Chemical	Dosage *mg/L*	Turbidity	Standard Plate Count Bacteria	Total Coliform Bacteria	Particle Count	*Giardia* Cysts
46	2.1	5.1	Sand (L)	HDE	37.4	3.0	None	None		27.3	-51.3	13.8	86	7.6
47	5.6	13.6	Dual (L)	HDE	37.4	3.0	None	None		-72.4	-66.6	25.0	99	§
48	2.0	5.0	Dual (L)	HDE	37.4	3.0	None	None		-18.2	-108.2	38.4	94	§
49	5.5	13.3	Sand (L)	HDE	35.6	2.0	None	None		-13.8	20.6	60.0	99	§
119	10.3	24.8	Dual (F)	CLP	37.4	3.0	None	None		18.8	9.7	5.3	90	41.9
120	8.0	19.2	Dual (F)	CLP	37.4	3.0	None	None		18.8	16.1	-7.5	86	36.4
121	5.1	12.4	Dual (F)	CLP	37.4	3.0	None	None		18.1	16.1	1.1	82	36.3
122	2.4	5.8	Dual (F)	CLP	37.4	3.0	None	None		15.6	99.6	99.9	82	68.3
69	5.6	13.6	Dual (L)	HDE	37.4	3.0	Nonoptimum	Alum,573C	15.0,1.1	73.6	78.8	99.9	-142.4	99.2
82	5.6	13.5	Dual (L)	HDE	37.4	3.0	Nonoptimum	Alum,572C	8.8,0.6	61.0	38.0	**	99.6	**
114	1.9	4.7	Dual (F)	CLP	37.4	3.0	Nonoptimum	Alum,572C	23.7,1.2	69.0	96.8	99.0	58.9	95.3
50	2.0	4.9	Sand (L)	HDE	39.2	4.0	Optimum	Alum,572C	2.1,0.9	88.9	82.3	>99.9	98.6	97.8
51	5.8	14.1	Dual (L)	HDE	37.4	3.0	Optimum	Alum,572C	4.1,1.7	86.1	85.4	83.0	98.9	99.1
52	2.1	5.1	Dual (L)	HDE	39.2	4.0	Optimum	Alum,572C	2.1,1.2	91.7	95.6	>99.9	99.2	99.7
53	5.7	13.9	Sand (L)	HDE	39.2	4.0	Optimum	Alum,572C	3.4,2.1	82.6	**	>99.9	93.8	99.5
70	5.5	13.3	Dual (L)	HDE	37.4	3.0	Optimum	Alum,573C	7.6,1.3	88.7	98.4	99.5	81.9	99.4
81	2.0	5.0	Dual (L)	HDE	37.4	3.0	Optimum	Alum,572C	6.8,0.9	85.4	97.8	99.9	98.3	**
104b	2.0	4.9	Dual (F)	CLP	38.3	3.5	Optimum	Alum,572C	13.4,0.6	82.4	99.5	79.8	98.6	98.7
106	2.1	5.1	Dual (F)	CLP	38.3	3.5	Optimum	8102N	0.5	-43.1	99.9	>99.9	87.0	39.5
107b	2.0	5.0	Dual (F)	CLP	37.4	3.0	Optimum	Alum,572C	11.3,0.5	92.7	96.7	90.0	95.4	>99.9
118	2.3	5.6	Dual (F)	CLP	37.4	3.0	Optimum	Alum,572C	23.7,1.4	85.5	98.4	99.4	**	97.6

*Sand (L)—sand obtained from Loveland treatment plant, 30-in. (76-cm) bed depth; dual (L)—11.8 in. (30 cm) of sand from Loveland and 17.7 in. (45 cm) of anthracite (Philterkal Special No. 1, Reading Anthracite Coal Co., Pottsville, Pa.); dual (F)—11.8 in. (30 cm) of sand from Fort Collins treatment plant and 17.7 in. (45 cm) of Philterkal anthracite

†HDE—water obtained from Horsetooth Reservoir, filtered by diatomaceous earth to give low turbidity (0.2-0.6 ntu); CLP—low turbidity raw water obtained from the Cache La Poudre River during the period September to April, when turbidity was generally 0.4-0.7 ntu

‡"Optimum" and "nonoptimum" are coagulant dosages producing filtered water turbidities that are minimum and greater than minimum, respectively.

§Removals of *Giardia* cysts were 96.3, 99.9, and 99.9 percent for runs 47, 48, and 49, respectively. These data are not shown in the table because the control samples of *Giardia* cysts for these runs deteriorated quickly. (Control samples were refrigerated and counted at the end of each run to determine whether significant losses had occurred as a result of deterioration. Most batches of cysts will remain intact for long periods under refrigeration, but some deteriorate easily.)

**No sample taken

TABLE 3

Effect of temperature on percent removals of turbidity, standard plate count bacteria, and total coliform bacteria for different chemical dosages

Run	Turbidity of Influent—*ntu*	Chemical	Dosage of Chemical *mg/L*	Temperature		Removal—*percent*		
				°F	°C	Turbidity	Standard Plate Count Bacteria	Total Coliform Bacteria
159	0.45	572C	0.42	41	5	33	90.0	97.0
151	0.45	572C	0.42	64.4	18	56	-77	86.6
160	0.45	Alum,572C*	4.31,1.85	41	5	78	95.89	99.5
152	0.45	Alum,572C*	4.31,1.85	64.4	18	82	77.6	>99
158	0.45	Alum,572C	5.47,0.48	41	5	56	93.7	99.7
154	0.45	Alum,572C	5.47,0.48	64.4	18	67	82.6	93.1
157	0.45	572C,alum	1.00,9.0	41	5	29	91.5	99.6
155	0.45	572C,alum	1.00,9.0	64.4	18	82	93.2	99.8

*Alum and polymer were added simultaneously using one rapid-mix basin.

eters, except particles, were uniformly low. The authors have no explanation for the higher percent removals of particles. For the nonoptimum chemical dosage, the percent removals were generally higher but not uniformly high. For the optimum chemical dosage, however, removals of all parameters were uniformly high, ranging from about 80 to >99.9 percent. The exception, run 106, was with a polymer commonly used as a filter aid for low turbidity waters. This result is included in the table to illustrate that high removals cannot be expected for some polymers. For the optimum chemical dosage, filtered water turbidity was generally about 0.05 ntu, with the removals ranging from 82 to 93 percent.

These results show that with "proper" chemical pretreatment, rapid rate filtration will remove more than 99.9 percent of *Giardia* cysts. Removals exceeded 97 percent for all filtration conditions when optimum chemical dosages were used. The results also show that when no chemicals are used, rapid rate filtration will work only as a simple strainer and will pass appreciable percentages of turbidity, bacteria, and *Giardia* cysts. As shown in Figure 3, if no coagulant chemicals are used, or if coagulants are used that are not well selected, removals of turbidity are erratic. The critical importance of proper chemical coagulation is thus demonstrated.

Figure 4 is a histogram that shows the percent removal of *Giardia* cysts with various coagulants. All data are shown, even those generated using effective coagulants but at nonoptimum dosages. The data indicate that alum with polymer 572C and alum with polymer 573C gave removals of ≥85 percent, with some removals of >99.9 percent. With no chemicals, high removals were not observed, thus corroborating the turbidity removal results.

Dosages of coagulants. Figure 5 is a "response surface" for filtered water turbidity as a function of alum and polymer 572C dosages. These data were obtained using the rapid rate filtration pilot plant (shown by the shaded bars) and a bench-scale filtration test procedure described by Choi[8] and Brink[9] (shown by the open bars). The jar filtration test utilized a conventional jar-test apparatus combined with six 2-in.- (5-cm-) diameter columns packed with 20 in. (50 cm) of dual media. After chemicals were added to the jars and mixed, the contents were poured through the dual media, using the same technique each time. The turbidity of the filtrate was measured and related to the coagulant dosages. The results were generally comparable with results from the laboratory-scale rapid rate filtration pilot plant.

Figure 5 shows that when alum is used with polymer 572C, filtered water turbidity levels can be reduced to 0.05 ntu (compared with raw water turbidities of about 0.5 ntu). The response surface did not seem to be strongly sensitive to either alum or polymer dosage. But it did show that either alum alone or polymer alone is not effective. The polymer dose used most often in the research was 1–2 mg/L, with alum dosages of 3–7 mg as $Al_2(SO_4)_3 \cdot 14\ H_2O$/L.

Figure 6 shows the percent removal of *Giardia* cysts for a range of polymer dosages; alum dosages in the range 0 to 15 mg/L are not indicated. The data show that removals were generally high, confirming the effectiveness of polymer 572C over a wide range of dosages.

Mode of filtration. Coagulation and flocculation of the low turbidity waters did not produce any visible floc unless high alum dosages were used. Therefore, conventional filtration, which by definition includes sedimentation, was not used. The experimental work was started with direct filtration; shortly after, the in-line filtration mode was tried. Comparisons of in-line filtration and direct filtration, with all conditions the same, resulted in filtered water turbidity levels of about 0.1 ntu for each mode. Based on these data, all further test runs were done with in-line filtration.

Media. Test runs were conducted to compare filtered water turbidity levels for a single medium (sand) and dual media (sand and anthracite). The first comparison was with no chemical pretreatment. With raw water turbidities of 0.5 ntu, filtered water turbidities were 0.4 ntu for both the single medium and the dual media. After 50 min of operation, head loss was 36 in. (92 cm) of water for the single medium and 21 in. (54 cm) of water for the dual media. Water temperatures were 35.6 to 39.2°F (2 to 4°C).

The second comparison was conducted using alum with polymer 573C at optimum dosages. Effluent turbidities were 0.04 ntu for both media, and again head loss was higher for the single medium.

Based on these results, the dual media was preferred because of lower head loss. Since no floc was discernible, the theory that the dual media is preferable because it permits floc penetration into the filter bed may not be applicable.

Filtration rate. Figure 7 shows the effect of hydraulic loading rate on percent removals of turbidity, standard plate count bacteria, total coliform bacteria, and *Giardia* cysts at optimum chemical dosages for dual media. Hydraulic loading rate had little effect on percent removals of total coliform bacteria. Even at 10 gpm/sq ft (25 m/h), the removal was 99 percent. Similar effects were seen for percent removals of standard plate count bacteria and *Giardia* cysts. The influence of hydraulic loading rate was stronger, however, for percent removal of turbidity.

These results indicate that hydraulic loading rates in the range 2 gpm/sq ft (4.9 m/h) to 8 gpm/sq ft (19 m/h) had little influence on percent removals of *Giardia* cysts and bacteria. An influence begins to become discernible, however,

at 10 gpm/sq ft (25 m/h). Pilot testing should be conducted to ascertain the influence of hydraulic loading rate for the conditions of a particular situation.

Temperature. Table 3 shows percent removals of turbidity, standard plate count bacteria, and total coliform bacteria at operating temperatures of 41 and 64.4°F (5 and 18°C) for four conditions of chemical pretreatment. The results show either no difference for the two temperatures or conflicting trends. If temperature has an influence, it does not seem to be great.

Surrogate indicators of *Giardia* cyst removal. Sampling of raw water or filtered water to recover *Giardia* cysts requires the passing of a large volume of water through a membrane filter, or fiber-wound filter, with a pore size small enough to strain the cysts. Whatever cysts are in the sample will be retained by the filter. Once the sample is obtained, a skilled technician is required to process it and to identify and count the cysts. Thus it is not likely that routine measurement of *Giardia* cysts can be incorporated into water treatment practice. A surrogate indicator of percent removal of *Giardia* cysts is desirable.

Several indicators, including turbidity, particles, standard plate count bacteria, and total coliform bacteria were investigated. Histogram plots were developed to relate percent removal of *Giardia* cysts to percent removal of turbidity and to percent removal of total coliform bacteria (Figures 8 and 9, respectively). Percent removals of particles did not show any relation to percent removals of *Giardia* cysts (Table 2).

Figure 8 shows that if turbidity removal is high, then removal of *Giardia* cysts will also be high. To be more specific, the plot shows 44 observations of turbidity removal >70 percent for low turbidity raw water. Of these 44 observations, 37 show removals of *Giardia* cysts >99 percent. In other words, if turbidity removal exceeded 70 percent and if filtered water turbidity was lower than 0.10 ntu, the probability was 0.85 (37/44) that the removal of *Giardia* cysts would equal or exceed 99 percent. Figure 8 shows only removals of *Giardia* cysts that exceed 85 percent. Eight observations of 0- to 85-percent removal of *Giardia* cysts are not shown, because of the scale selected, for the <40-percent removal of turbidity.[2]

With some 68 pairs of data (of percent removal of turbidity and percent removal of cysts), it can be said that when turbidity removal is high, then cyst removal can be expected to be high also. The comparisons show unequivocally that when raw water turbidity levels are about 0.5 ntu, high removals of *Giardia* cysts, i.e., >99 percent, can be expected with high removals of turbidity, i.e., >70 percent. Thus, for the case of filtration of

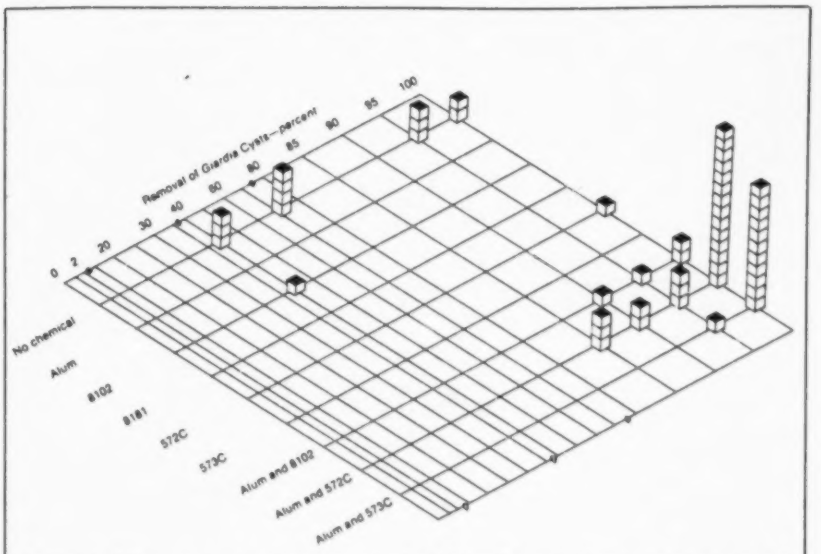


Figure 4. Histogram of percent removal of *Giardia* cysts for coagulants tested *(each block represents one set of measurements; number of test runs—52; raw water turbidity—0.5-1.5 ntu; temperature—37.4-41°F [3-5°C])*

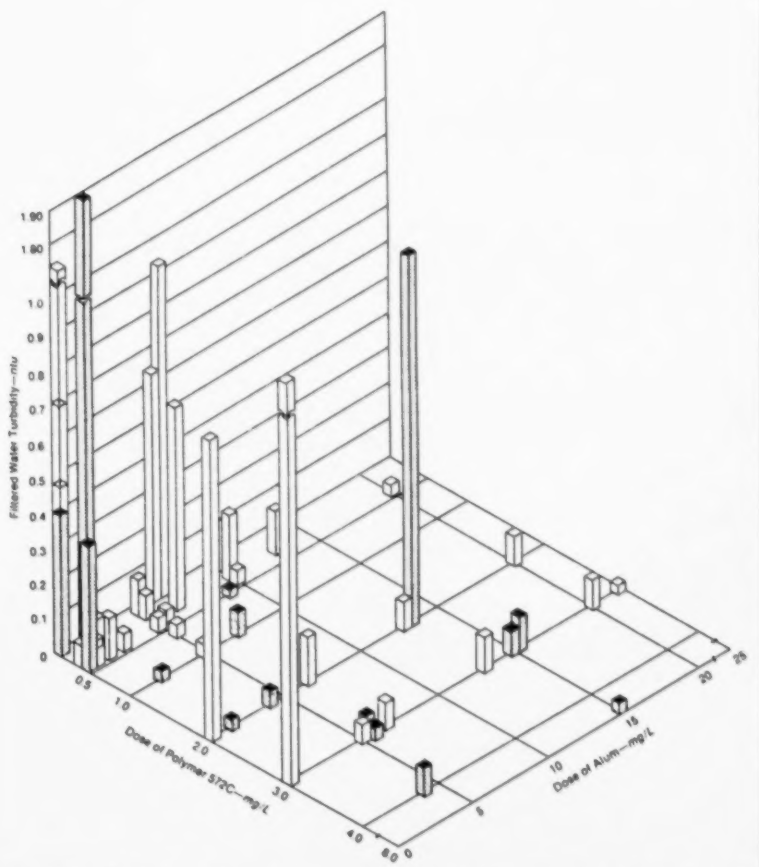


Figure 5. Turbidity of filtered water for various combinations of alum and polymer 572C *(shaded bars—results obtained with laboratory-scale pilot plant; open bars—results obtained with bench-scale filtration apparatus; number of test runs—15; raw water turbidity—0.2-2.5 ntu; temperature—37.4-39.2°F [3-4°C])*

low turbidity water, percent removal of turbidity can serve as a surrogate indicator of percent removal of *Giardia* cysts.

Figure 9 shows that if high percentages of total coliform bacteria are removed by the filtration process, then high percent removals of *Giardia* cysts can be expected also. The analysis of the data in Figure 9 would be similar to the analysis of the data for Figure 8.

Although Figure 9 indicates that percent removal of total coliform bacteria would be a good indicator of percent removal of *Giardia* cysts, the use of total coliform bacteria may not be practical for water treatment plants using mountain streams as a source of supply. In such streams, concentrations of total coliform bacteria may be <100 organisms/100 mL. Therefore, to evaluate filtration performance for such raw water sources, a pilot filter would have to be operated alongside the full-scale filter and spiked with raw sewage. The coliform bacteria would then be abundant enough to permit accurate measurement of their removal. Turbidity, on the other hand, is easy to measure. Even if raw water turbidity is <1 ntu, turbidity removal can be measured accurately enough to serve as a reliable index of filtration efficiency.

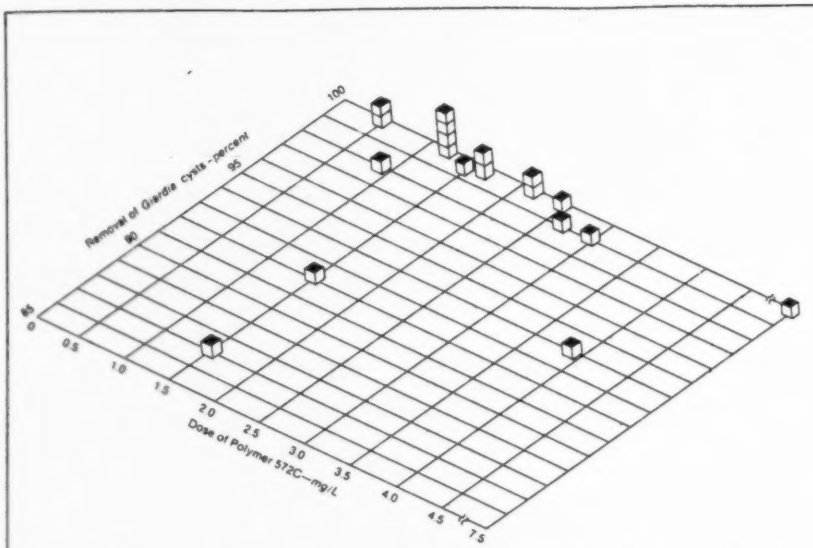


Figure 6. Histogram of percent removal of *Giardia* cysts for different polymer 572C dosages *(each block represents one set of measurements; number of test runs—19; raw water turbidity—0.36-2.5 ntu; temperature—35.6-39.2°F (2-4°C); primary coagulant—0-15 mg alum/L)*

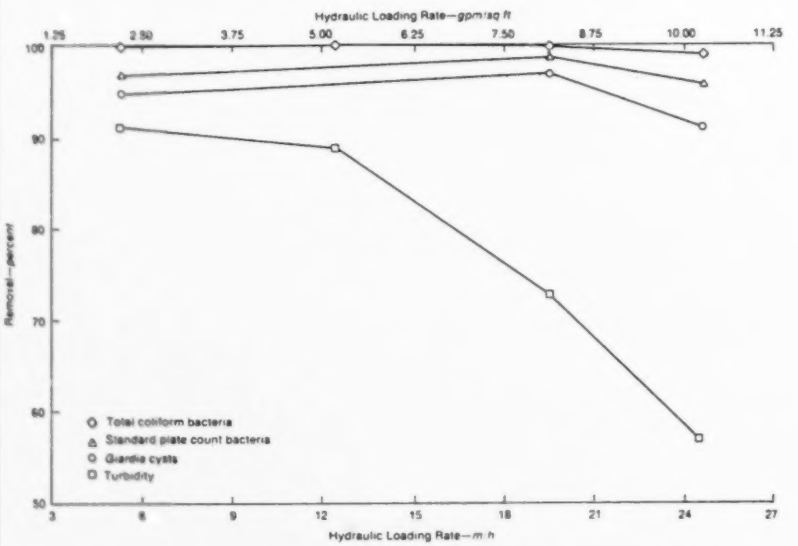


Figure 7. Effect of hydraulic loading rate on percent removals of turbidity, standard plate count bacteria, total coliform bacteria, and *Giardia* cysts *(run numbers—111-114; raw water turbidity—1.1 ntu; temperature—37.4° [3°C); primary coagulant—18.6 mg alum/L for runs 111-113, 23 mg alum/L for run 114; secondary coagulant—1 mg 572C/L)*

Conclusions

The results of this research show that proper chemical pretreatment is imperative if the rapid rate filtration process is to be effective for low turbidity waters. Selection of the proper coagulant aid polymers to use with the primary coagulant, such as alum, is most important, as is the use of the proper dosages to achieve high reductions of turbidity. With proper chemical pretreatment, removals can be expected to exceed 70 percent for turbidity, 99 percent for bacteria, and 95 percent for *Giardia* cysts. With no chemical pretreatment, removals of *Giardia* cysts, bacteria, and turbidity can be expected to be in the range of 0 to 70 percent.

Other process variables were not as important as chemical pretreatment. In-line filtration was found to be as effective as direct filtration and is recommended. A single medium of sand and dual media of anthracite and sand were found to be equally efficient for reducing turbidity and bacteria. Hydraulic loading rates in the range 2 gpm/sq ft (4.9 m/h) to 8 gpm/sq ft (19.2 m/h) had little effect on percent removals. At 10 gpm/sq ft (25.2 m/h), a moderate detrimental effect was seen. Investigation of the effect of temperature showed no trend in percent removals of turbidity, bacteria, and *Giardia* cysts at 41°F (5°C) compared with 64.4°F (18°C). Further work is recommended in this area.

Analysis of the data by means of histograms showed that either percent removal of turbidity or percent removal of total coliform bacteria could serve as a surrogate indicator of percent removal of *Giardia* cysts. If, for example, raw water turbidity is 0.5 ntu and if removal of turbidity is 70 percent or greater, the probability is 0.85 that removal of *Giardia* cysts will exceed 99 percent. The use of pilot filter columns spiked with coliform bacteria alongside the full-scale filters is recommended for proper evaluation of the filtration of low turbidity waters.

For rapid rate filtration of low turbidity waters, the results of this study show that proper chemical pretreatment is necessary to adequately remove various particles, including *Giardia* cysts; that percent reduction of turbidity can serve as a surrogate for removal of other particles, including *Giardia* cysts; and that proper coagulation can be achieved.

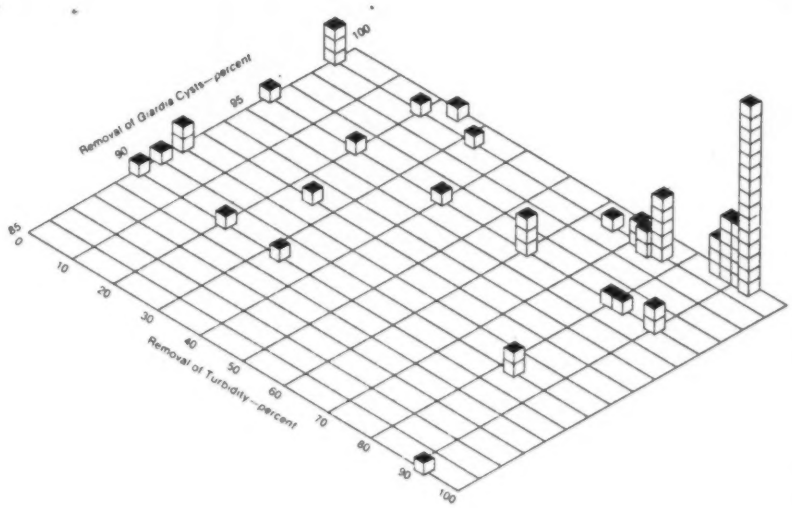


Figure 8. Histogram showing relationship between percent removal of *Giardia* cysts and percent removal of turbidity *(each block represents one set of measurements; number of test runs—65; raw water turbidity—0.2-1.0 ntu; temperature—37.4-41°F [3-5°C])*

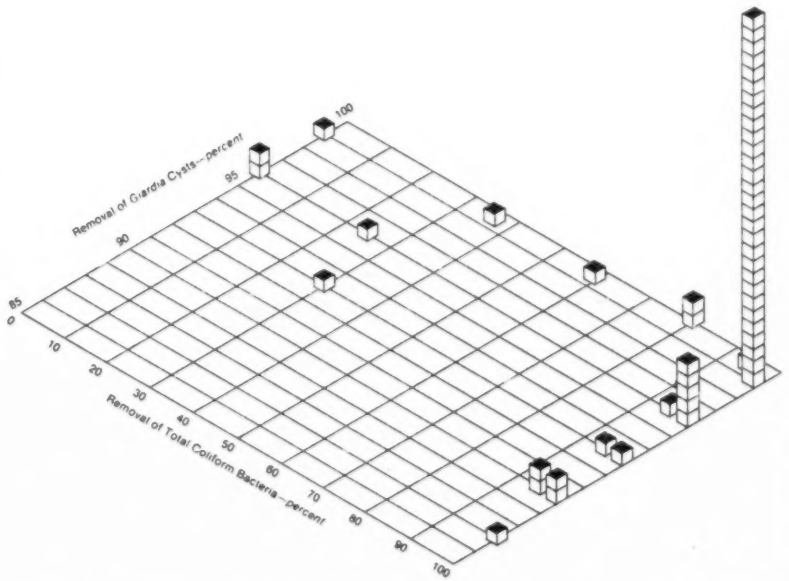


Figure 9. Histogram showing relationship between percent removal of *Giardia* cysts and percent removal of total coliform bacteria *(each block represents one set of measurements; number of test runs—51; raw water turbidity—0.2-3.0 ntu; temperature—37.4-41°F [3-5°C])*

Proper coagulation, however, requires careful selection of chemicals and dosages.

Acknowledgment

The research was conducted through support from Cooperative Agreement CR80865-02 between Colorado State University, Ft. Collins, Colo., and the Drinking Water Research Division, US Environmental Protection Agency, Cincinnati, Ohio. Analyses of samples for *Giardia* cysts were conducted under the direction of Charles P. Hibler, professor of pathology, Colorado State University. Bacteria samples were analyzed by Donna Howell and Roy Warbington, Department of Microbiology, Colorado State University. The late Sumner Morrison, professor of microbiology, Colorado State University, served as consultant on microbiology.

References

1. KARLIN, R.J. & HOPKINS, R.S. Engineering Defects Associated with Colorado Giardiasis Outbreaks, June 1980-June 1982. *Proc. 1983 AWWA Ann. Conf.*
2. AL-ANI, M.Y ET AL. Filtration of *Giardia* Cysts and Other Substances. Vol. 3: Rapid Rate Filtration. Envir. Engrg. Tech. Rept. 5847-84-4, Dept. of Civil Engrg., Colo. State Univ., Fort Collins (Oct. 1984).
3. LUCHTEL, D.L.; LAWRENCE, W.P.; & DEWALLE, F.B. Electron Microscopy of *Giardia lamblia* Cysts. *Applied & Environmental Microbiology*, 40:4:821 (1980).
4. BELLAMY, W.D.; LANGE, K.P.; & HENDRICKS, D.W. Filtration of *Giardia* Cysts and Other Substances. Vol. 1: Diatomaceous Earth Filtration. Environmental Engineering Technical Report 5847-84-1. Department of Civil Engineering, Colorado State University, Fort Collins (Mar. 1984).
5. BELLAMY, W.D.; SILVERMAN, G.S.; & HENDRICKS, D.W. Filtration of *Giardia* Cysts and Other Substances. Vol. 2: Slow Sand Filtration. Environmental Engineering Technical Report 5847-84-3. Department of Civil Engineering, Colorado State University, Fort Collins (Oct. 1984).
6. DAVIES, R.B.; FUKUTAKI, K.; & HIBLER, C.P. Cross Transmission of *Giardia*. US Environmental Protection Agency Report PB83-117-747. Cincinnati, Ohio (Jan. 1983).
7. Microbiological Methods for Monitoring the Environment, Water and Wastes (R. Bordener and J. Winder, editors). US Environmental Protection Agency Publication 600-18/78-017. Cincinnati, Ohio (1978).
8. CHOI, S. Coagulation of Low Turbidity Water. Master's thesis, Department of Civil Engineering, Colorado State University, Fort Collins (1983).
9. BRINK, D.R. The Jar-Filtration Test as a Bench-Scale Evaluation of Coagulants for Low Turbidity Waters. Master's thesis, Dept. of Civil Engrg., Colorado State University, Fort Collins (1984).

About the authors: *Mohammed Y. Al-Ani, currently a research engineer with the Scientific Research Council, P.O. Box 2371, Jadirayh Baghdad, Iraq, spent six years at Colorado State University, Fort Collins, where he conducted research into rapid-rate filtration and the removal of* Giardia *cysts and earned master's and doctoral degrees. David W. Hendricks* is professor of civil engineering, Engineering Research Center, Colorado State University, Fort Collins, CO 80523. Gary S. Logsdon is chief of the Microbiological Treatment Branch, Drinking Water Research Division, USEPA, 26 W. St. Clair St., Cincinnati, OH 45268. Charles P. Hibler is a professor in the Department of Pathology at Colorado State University.*

*To whom correspondence should be addressed

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

This article documents research that was conducted under the auspices of the U.S. Environmental Protection Agency (USEPA). As an arm of the government, the USEPA has a paid up, non-exclusive, irrevocable, worldwide license to reproduce, prepare derivative works, and distribute to the public all of the material contained herein, and to grant others acting on its behalf the right to do so. The USEPA grants to the National Technical Information Service, Department of Commerce, the right to act as its agent in the distribution of this material.